SIMULATION AND MODELING OF THE CONSTRUCTION OF A MOBILE OFFSHORE BASE

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ABSTRACT

There are many ways to determine the feasibility, schedule, and cost of constructing unique structures. In recent years, modeling the activities involved and running simulations of various options has become a useful tool for such assessments. In this paper, we discuss two different efforts to model the construction of the McDermott concept for the Mobile Offshore Base (MOB), a very large floating logistical base for humanitarian and military deployments in underdeveloped or hostile environments. The MOB is composed of multiple similar units connected together to form a base of the required size. The efforts, both funded through the U.S. Navy MOB Program, were performed in 1998 by McDermott Technology, Inc. and in 1999 by the University of Maryland's Center of Technology and Systems Management. The efforts model both the construction of one of the individual units and the integrated construction of multiple units.

Both efforts began with the assumption that a project of this size would require work to be performed in many shipyards in parallel, with final integration occurring toward the end of the construction period. Therefore, both efforts broke the overall design into work/ship units for construction in many shipyards. One effort assigned the work units based on the assumption that the largest number of shipyards possible would be involved, simultaneously increasing the geographic spread of (and support for) the project and reducing the impact of any one yard's on-going backlog or its failure to perform as planned. The second effort assigned the work based on a desire to minimize the number of shipyards involved, reducing the construction and schedule management complexity.

Despite these differences, the two efforts arrived at remarkably similar (±10%) estimates of the construction time for a single unit. Furthermore, the two efforts arrived at similar answers for the integrated construction of multiple units when the same assumptions about construction philosophy and yard capacities were made.

Statistical variation in the assumed construction productivities and other overall risk sources were simulated to determine the impact of such typical variabilities on the calculated schedule. As expected, the simulations showed that each strategy had its strengths and weaknesses but that possible sources of significant project delay could be identified and managed through planning and the use of simulation.

This agreement between independent groups with different ultimate uses for the models and different assumptions about work allocation supports the idea that the MOB is constructable in reasonable time frames and that simulation is an extremely valuable and believable tool for assessing construction feasibility, schedule, and cost for large, unique, floating structures.

INTRODUCTION

Mobile Offshore Base (MOB) refers to a large floating logistical supply platform with military and humanitarian applications that could be prepositioned and/or repositioned as needs changed. For those supply and resupply scenarios that involve land-based cargo aircraft, such a base would need to support a runway length of approximately 1500 meters. To achieve such a runway within reasonable extrapolations of existing offshore technology, McDermott, working as part of the U.S. Navy's Office of Naval Research (ONR) program to investigate the feasibility of such a platform, has proposed a solution using five, 300-meter–long, semisubmersible single-base units (SBUs).

Figure 1 is an artist's conception of McDermott's proposed Mobile Offshore Base showing the five interconnected semisubmersible SBUs. A single SBU is 300 meters long, 152 meters wide, and 75.6 meters high (from keel to flight deck). Each SBU has approximately 90,000 square meters of configurable warehouse space and is capable of carrying 30,000 metric tons of cargo at 15 knots when drafted to 13 meters (up on the ship-shaped lower hulls) or up to 60,000 metric tons at slightly deeper draft and lower speed. On station, the SBUs are ballasted to 39 meters and attached together at the upper hulls. The connectors to accomplish this are designed to release all rotational degrees of freedom but maintain intermodular alignment for aircraft operations in significant wave heights of up to 4 meters.

The overall length of a fully configured MOB is the required 1500 meters. This is long enough to permit air operations with land-based cargo aircraft up to the size of a U.S. Air Force C-17. Additional SBUs could be added if it is desirable to handle aircraft with longer field requirements.

In addition, each SBU is equipped with three cargo cranes, one on the port side and two on the starboard. The port side also has a loading platform to receive ramps from roll-on/roll-off (RO/RO) ships and to serve as an artificial "beach" for smaller deployment/assault vessels. These facilities can service most commercial 1000–1500 TEU container ships or RO/RO vessels in addition to the military sealift fleet. For example, it is estimated that the cranes could unload a 1200-TEU container vessel moored to the starboard side in 30 hours in sea state 2 or in 45 hours in sea state 4.

Each SBU represents an approximately 50% increase in dimensions compared to the largest currently deployed semisubmersibles. However, each SBU is large enough that current standard ship construction techniques and facilities could not be used to build it. Problems such as dry-dock capacity and dimensions, harbor clearances, plate steel requirements, steel fabrication volume, and timely completion of multiple units require careful investigation to ensure that such a project is possible not only from a naval architecture point of view, but also from those of construction, fabrication and deployment.

SBU BUILD STRATEGY

Fortunately, McDermott and other offshore industry construction firms have developed ways to assemble floating structures of this magnitude without the use of traditional shipyard practices.

The key elements of these strategies are:

- Modular construction at multiple locations, and
- Final assembly on the water

Figure 1 Five-unit Mobile Offshore Base

For example, Figure 2 shows the final mating of the Auger tension-leg production platform currently operating in the Gulf of Mexico. The upper deck assembly, weighing about 20,000 metric tons, has been brought on a barge and is being mated with its flotation and mooring structure. These two major parts were assembled separately on land at geographically dispersed locations and then brought to this offshore assembly location for final mating and weldout. In this case, the production deck was floated over a ballasted flotation section. The flotation section was then deballasted, lifting the deck off its transportation barge. The only offshore welding required was to attach the deck to its flotation hull.

The general SBU build strategy is to break the vessel down into major components, each of which can be constructed in existing facilities in parallel and to devise a method for assembling these components on the water. Figure 3 shows the breakdown envisioned. The lower hull assemblies are product-tanker-sized hulls of roughly 20,000 metric tons displacement each. The columns, which are rectangular with rounded corner elements, are roughly 1,800 metric tons each. The brace sets, each consisting of a horizontal brace and two vertical diagonals, are about 900 metric tons per set. All of these assemblies can be built in numerous shipyard and steel fabrication facilities with ready access to water or rail transportation. Furthermore, the individual bracing elements are all small enough that existing offshore construction derrick barges can be used to lift them from transportation barges into position for final assembly at sea.

The major problem is the upper hull, a rectangular cross section object 300 meters long, 152 meters wide, and 24.6 meters deep and weighing over 80,000 metric tons. As noted earlier, the Auger platform was assembled by floating and attaching a roughly 20,000-metric-ton deck to its lower floatation system. The obvious solution seemed to be to break the upper hull into four 20,000–metric-ton grand blocks and attach them one at a time in the final assembly sequence using the same float-over technique used for the Auger platform.

The construction strategy can be summarized as follows:

Figure 2 Mating of upper and flotation hulls of auger TLP

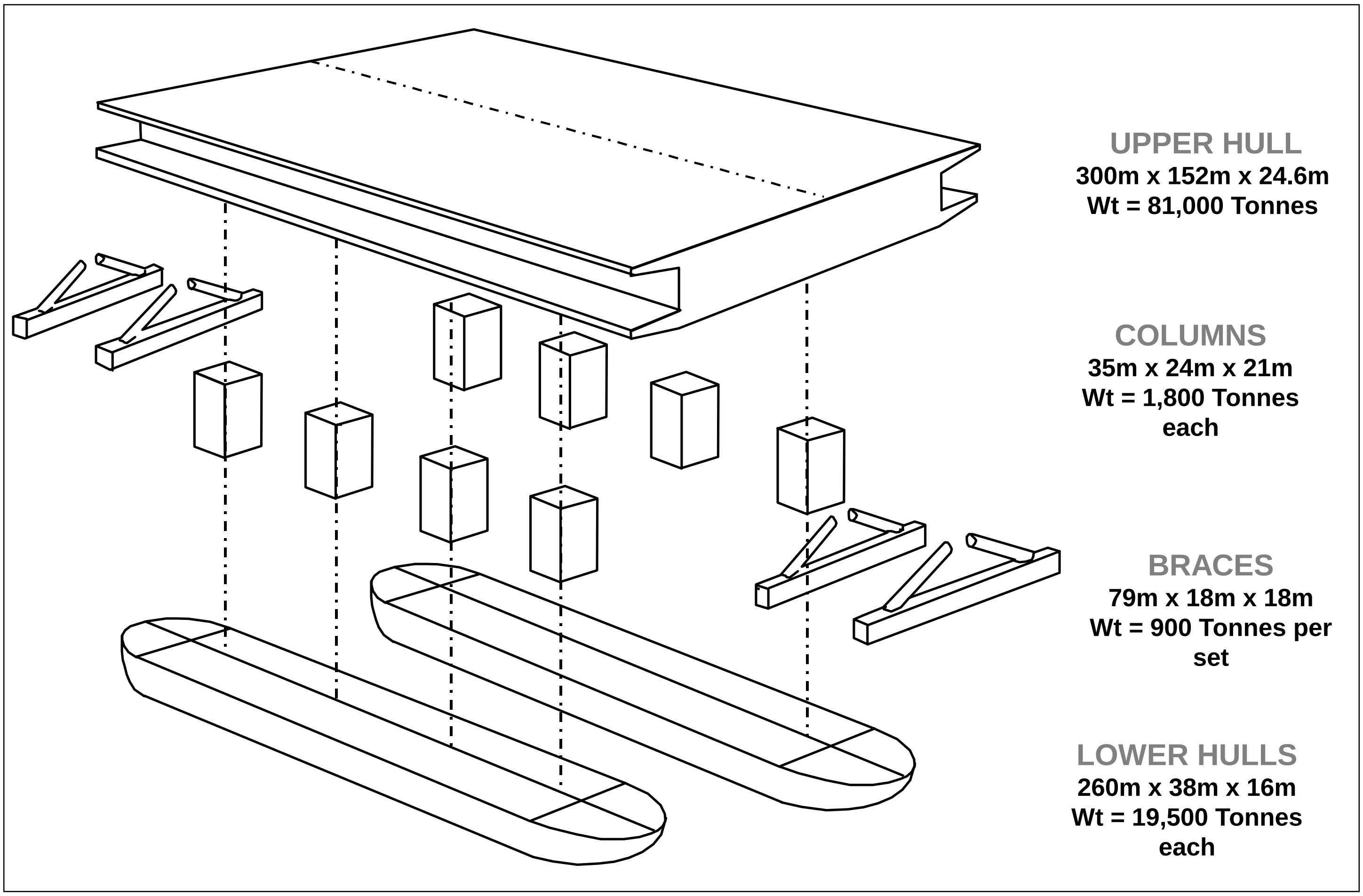

Figure 3 MOB major components

- Build lower hulls in traditional manner in conventional shipyards
- Fabricate columns and bracing elements in any of numerous steel fabrication or shipyard locations with accessible water transportation
- Assemble the lower hulls, columns, and horizontal braces into a floating platform ready to receive the upper hull grand blocks
- Use the float-over techniques and construction barges of the Auger deployment to attach the four upper hull blocks, one at a time, to the lower floatation platform

Implementing this strategy and modifying its details is the focus of the simulations that are reported here. The purpose of these simulations was to:

- Gain insight into the feasibility of the proposed strategy.
- Estimate the time, materials, and labor requirements for the construction.
- Develop insight into the risks and concerns that such an unparalleled maritime construction would present to its planners and contractors.

ASSEMBLY STRATEGY MODEL (ASM)

The assembly strategy model is a hierarchical discrete-event simulation model developed in the ARENA simulation language by McDermott to demonstrate that the concept of multiple-yard fabrication and at-sea assembly was a feasible construction methodology for the MOB. Currie *et al.* (1998) describes the model and how it was used to verify anticipated fabrication schedules and interactions between supplier yards during the construction of a single, isolated SBU. Since that time, the model has been expanded to analyze the construction of multiple SBUs as in a campaign to construct an entire MOB or multiple MOBs.

Construction Breakdown

The first step in developing this model was to break the high-level modules described above into component pieces and investigate how they could be constructed in conventional facilities. Currie *et al.* (1998) contains a description of the breakdown used in this analysis. The underlying assumption used in the selection of the number and type of facilities involved was that it was desirable to limit the number of yards involved. This assumption was made to minimize the construction management risk and maximize the motivation in each yard to meet or exceed schedule and cost objectives.

Given normal yard capacities, it was thought best to assign each lower hull to one shipyard (two yards); to build columns in sets of four, one set per yard (two yards); to fabricate all the braces in a single yard (one yard); and to use three yards to fabricate the upper hull blocks. A single grand block assembly location (one yard) capable of simultaneously fabricating four grand blocks would complete the required facilities (total of nine locations) for a single SBU construction. As will be seen later, when we moved to multiple SBU construction, it became necessary to add more grand block assembly facilities (total of 11 locations).

Modeling Technique

McDermott adopted a hierarchical modeling scheme for this work by building two different simulation models: one of the lower level "feeder yards" and a second of the final assembly activity that models the grand block assembly and offshore assembly operations. In essence, the feeder yard models provided construction estimates on a per-shipping-unit basis. Using these construction times as input data, the overall SBU assembly model ran much more rapidly than if all the lower-level work were simulated in detail each time. In this overall model, the outputs of each feeder yard fed the grand block assembly locations, which in turn fed the offshore, at-sea final integration steps.

Figure 4 is an animation screen snapshot from the overall ASM construction simulation showing yards, components, and material at a point just over one year into the fabrication of the first SBU.

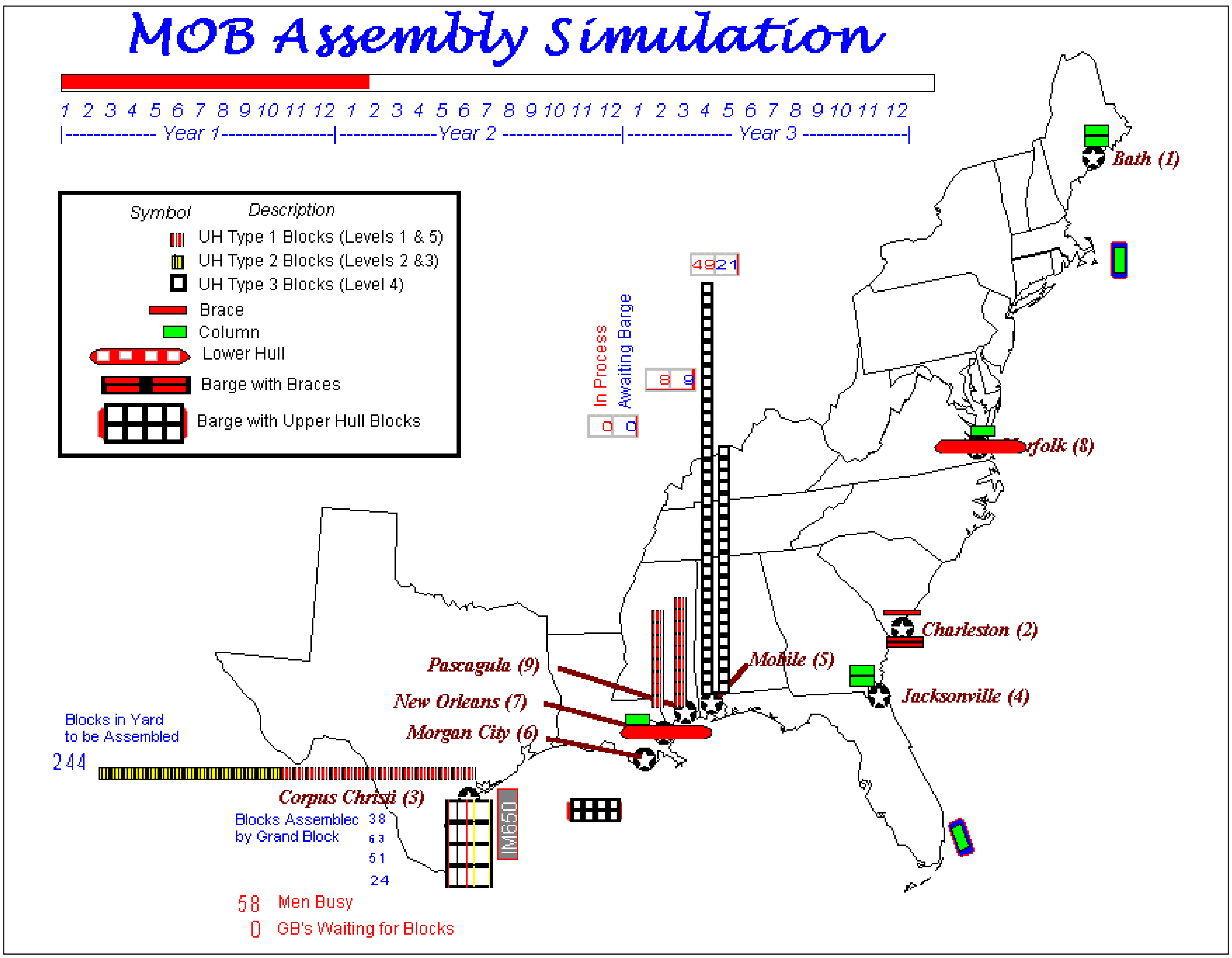

Figure 4 MOB assembly strategy model simulation screen

Multiple Module Construction

The simulation of multiple-unit construction required some investigation of when each yard could begin work on the second (and subsequent) modules following the completion of its predecessor's components. The single longest construction time is that for the lower hulls. Conventional wisdom and current practice suggests that commercial construction of a series of identical product tankers in a single U.S. shipyard would yield a time between hull launches of up to 1 year. It was assumed that this schedule experience would hold for the lower hulls of the MOB, and efforts were made to identify if the remainder of the feeder yards and the grand block assembly location could meet the same one-year interval between SBUs.

The results of this investigation indicated that only one portion of the construction capacity required expansion to maintain the one year between launchings — the grand block assembly space. An additional four skidways were necessary. Given the specific capacities of existing Gulf of Mexico yards, this meant that two additional grand block assembly locations needed be added to the nine locations used in fabricating the first SBU.

A further motivation to keep one-year intervals is that it places the offshore assembly activity in the same season of the year (same seasonal weather) for all modules. This means that similar weather issues should be experienced on all constructions and that a learning curve might occur even for this difficult activity.

The overall simulation for multiple units consisted of:

- Launching lower hulls from their two parallel construction yards at one-year intervals following the first hull's completion at 18 months.
- Keeping the six feeder yards continuously working on components for successive SBUs.
- Assigning upper hull grand block assembly to three different yards.
- Performing the at-sea integration at the same offshore site on yearly intervals.

For purposes of the simulation, the location of the assembly yards was not important, but some effort was made to segregate the grand blocks with similar construction problems (external connectors, elevators, etc.) into the same yard to reproduce the likely assignments that would be made in actual practice.

Other variations in work assignments that reflected the desire to minimize exposure to weather-related construction risk were introduced into the multiyard scenario. Since they do not affect the results of interest here, they will not be detailed in this paper. However, they do indicate the usefulness of simulation in studying alternative construction plans and identifying risk reduction strategies.

Analysis Methods

The discrete-event models described above can be run in two modes — deterministically and with production uncertainties. In deterministic analysis, estimates of fabrication times derived from the feeder yard simulations are fed directly into the overall simulation, where point estimates for grand block assembly and at-sea integration produce a single "time to complete." In the uncertainty analysis, these fabrication estimates and the productivity of the grand block assembly and final integration steps can be assigned using statistical probability distributions to represent construction variability. In this case, multiple runs that randomly sample the variability at each stage of construction create an ensemble of results that can be analyzed statistically to determine a mean "time to complete" with standard distributional statistics about that mean.

Determining the appropriate distributions to model the uncertainties usually is done based on prior construction experience. However, we had no statistics on the actual fabrication of these components. The distribution form commonly used in such situations is the triangular distribution, characterized by a lower bound, an upper bound, and a most likely value. Test runs made using this distribution to represent the variability in the processing times of the feeder yards' individual shops verified that the output of these yards could also be represented using a triangular distribution. The overall assembly model used triangular distributions for the feeder yard outputs, the grand block assembly processing times, and the at-sea integration work rates. Various assumptions on the lower and upper bounds were used for each distribution. Some 2,000 replications of each set of assumptions provided the statistical results that were analyzed to produce the ensemble averages discussed in the Results section that follows.

RISK ANALYSIS MODEL (RAM)

The University of Maryland Department of Civil and Environmental Engineering developed models of the MOB construction process whose purpose was to determine construction feasibility of competing MOB design concepts. The study involved two major phases — defining construction systems and performing a risk analysis. Although the risk study investigated other concepts, this paper will report only the work done on the McDermott concept and the afloat assembly procedure described above. This alternative was based on construction using existing U.S. infrastructure and offshore assembly techniques. (See Ayyub *et al.*, 1999a, for a complete description of the other alternatives investigated and the construction systems associated with all concepts.)

Initial Feasibility Evaluation

The construction capabilities of the U.S. marine industry were compared to the construction resource requirements for a MOB to provide an initial concept feasibility determination.

Construction costs and schedule estimates were developed using a database of production indexes for U.S. Navy shipbuilding and from other published sources (McDermott 1997, NAVSEA 1998, and Aker 1997).

In a manner similar to the ASM described previously, the MOB was broken into blocks and components and assigned to ship and fabrication yards. In this case, the attempt was to maximize the number of yards involved to increase support for the program and to lower the risk of any single failure to perform affecting the entire program. The concept was modeled as being assembled from components or blocks built at 20 separate shipyards or offshore construction facilities located on the Pacific, Atlantic, and Gulf coasts of the U.S. The grand blocks are assembled on the Texas Gulf coast, and offshore assembly was planned for deeper water in the Gulf of Mexico. This initial review showed no glaring mismatch between needs and capacities and enumerated the areas that needed further intensive investigation in the full-risk analysis phase.

Full-Risk Analysis

The objective of the RAM construction analysis was to determine the construction cost and schedule feasibility issues and create an overall optimum estimate of time and cost. The complete MOB construction risk analysis is presented in Ayyub *et al.* (1999b). The analysis here was much more rigorous than in the initial feasibility determination described above and used hierarchical modeling to simulate construction. The simulation developed a mean and standard distribution for cost and schedule. These models and statistics were then used in a decision analysis framework to obtain optimum cost and schedule. The process used in the risk analysis for MOB construction is shown in Figure 5.

The following risk areas are accounted for in the construction simulation:

- **Cost and Schedule** — Account for uncertainty in "point" estimates developed in construction systems definition.
- **Labor** — Marginal strength to construct a MOB and potential competition from existing or future backlog in the shipbuilding and offshore industries.
- **Safety** — High accident or injury rate could impact cost and schedule.
- **Environmental** — Potential delay and cost for environmental studies and mitigation.
- **Construction Management** — The integration and schedule issues of combining many components from 20 different facilities.

MOB Model and Simulation Set Up

Discrete-event simulation is used to probabilistically assess possible outcomes of cost and schedule by using statistics to account for the effects of variances and randomness. The model accounts for sequences, construction times, transportation, fabrication, and assembly. By accounting for uncertainty, outputs of cost and schedule are developed with associated probabilities.

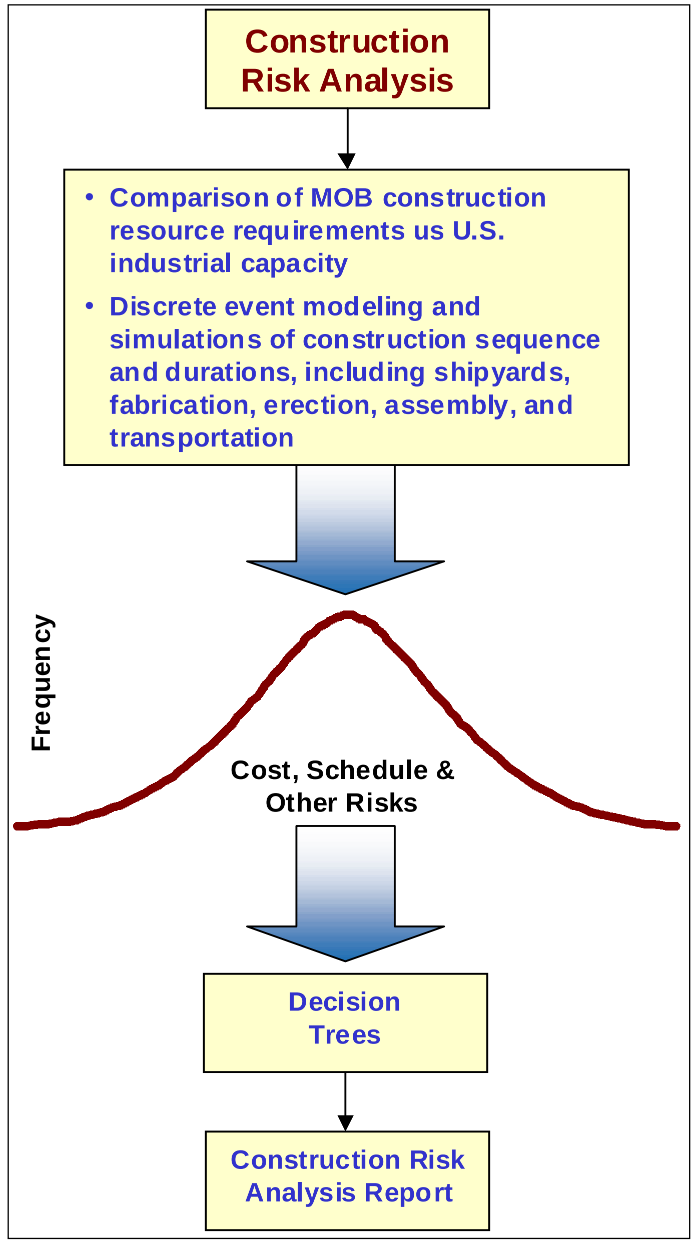

Figure 5 Construction risk analysis.

Using the critical-path method of construction scheduling, the model was built according to the scenario developed in the construction systems definition. The discrete-event simulation package selected for this work was Extend™ by Imagine That,® Inc. Input distributions used in the model are based on the particular construction activity. For example, building blocks for the upper hull was represented by a beta distribution that represented the conservative estimate derived in the construction systems estimate. Selection of other input distributions were based on a review of construction modeling research (AbouRizk and Halpin, 1992) or application of a particular distribution's characteristics combined with personal construction knowledge.

An important step in model building and simulation is verification and validation. Models were built using a collaborative and iterative approach: one person would propose a model; another would critique the model and make or propose necessary changes to it. To verify the model, simulation results were compared to the estimate found in the construction systems definition. Patterning models after the critical path schedule validated the model. The simulation also took learning curve efficiencies into account, and the influence of a construction management risk was incorporated into the model with a fuzzy analysis technique (Blair *et al.*, 1999).

The MOB construction scenario shown in Figure 6 was modeled and simulated. The heavy lines are the critical path, and light lines signify normal precedence. Each block in Figure 6 is further broken down into a hierarchy of blocks and/or probability distributions that change the attributes of cost and schedule as MOB construction is simulated. For example, the " Lower Hulls" block represents building the lower hulls at a shipyard, and a single beta distribution represents the duration of this construction. On the other hand, the block "Blocks for GB1" represents seven different types or quantities of subassemblies built at five different shipyards for incorporation into a Grand Block (GB). Each of these subassembly shipyards is represented by beta distributions that mimic the duration of a particular construction activity.

To ensure valid statistics, the construction was simulated with 2000 replication runs, each providing different results due to the random selection of values from the probability distributions. Schedule and cost simulation results were then computed from these simulation data using the central-limit theorem.

RESULTS

Single Module

Using the ASM, the deterministic analysis found a time frame of 30 months necessary to construct a single module. The RAM, statistically analyzing the results of 2,000 runs, determined the single-module construction time of 36 months (35.5 minimum and 37.5 maximum). This agreement is quite remarkable, given the different assumptions and construction strategies. It gives strong support to the idea that the single module could be constructed in 33 months, ±3 months.

Multiple Modules

Since a full MOB consists of five SBUs, the multiple module ASM simulation was carried to the point at which five SBUs were completed. The deterministic analysis yielded the expected result: 30 months for first module and 12 months each for the succeeding four modules, yielding a total of 6.5 years. The uncertainty analyses used several different assumptions about the productivities in the feeder and grand block assembly areas. Combining the results of these analyses resulted in an estimate of 6.5 years (6.3 years minimum and 6.9 years maximum).

The RAM did not simulate multiple SBU constructions directly but instead examined multiple module construction by simply assuming different levels of overlap between the schedules for the single modules. An earlier risk analysis study (Ayyub *et al.*, 1999b) applied a 30% overlap to all concepts studied. Detailed analysis of the critical path for the McDermott concept indicates an overlap of 60% is achievable. Further modeling and analysis could be performed to obtain a statistically derived schedule overlap.

Figure 7 shows the results of different assumptions about overlap in the single-unit schedules — from the very conservative 30% to a highly aggressive 80%. Two lines are plotted — one assuming a 36-month SBU schedule derived

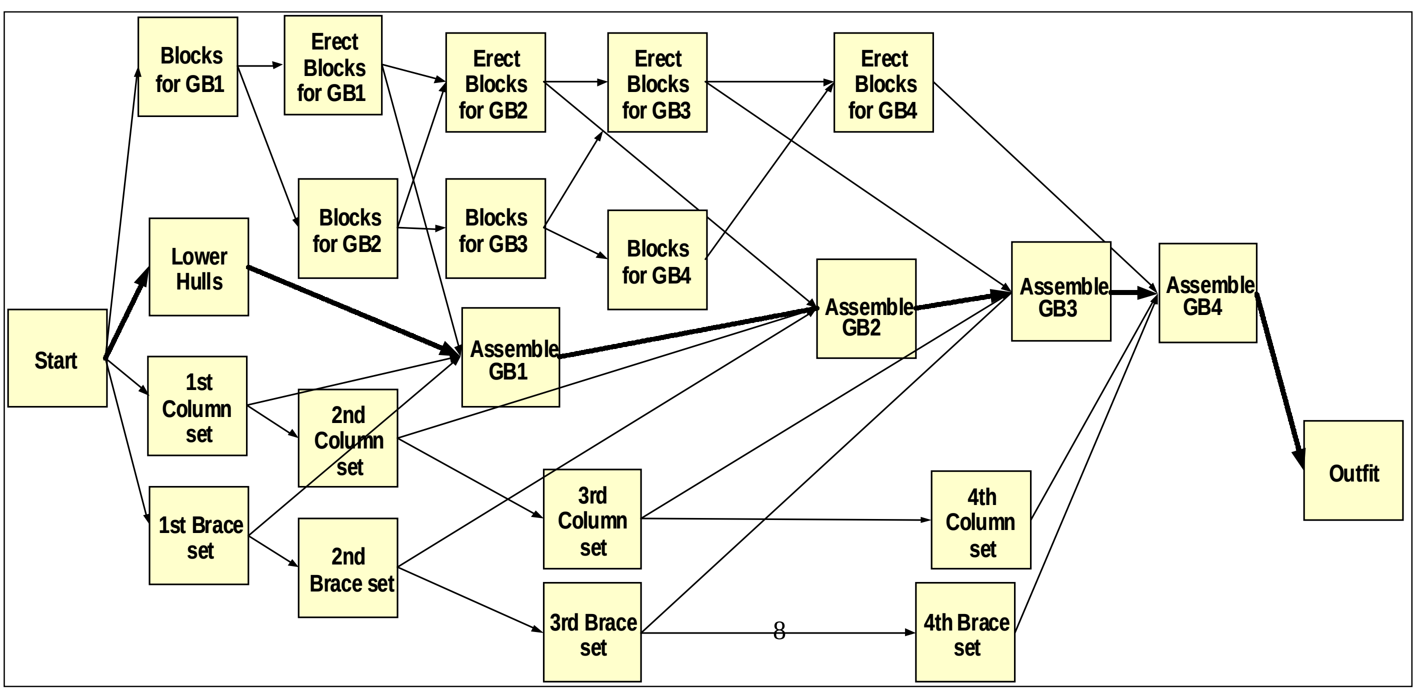

Figure 6 McDermott afloat assembly scenario

from the RAM and the second assuming the 30-month SBU timeframe from the ASM. The ASM results suggest that a 60% overlap represents an easily achievable level. Figure 7 indicates that this means the multiple-unit MOB could be completed in 6.5 to 8 years from start of construction.

SUMMARY

The work described here supports the belief that discrete-event simulation is an excellent way to investigate new, innovative construction plans. Models created for very different purposes and with quite different assumptions on work assignments provided similar bottom-line conclusions on the time required to construct a totally unique floating structure.

Also, the models identified areas in each of the assumed methods of work assignment that would have significant impact on the overall construction schedule and that should receive priority in initial planning and during project execution.

Specific conclusions that can be drawn regarding the MOB:

- It can be built in reasonable timeframes without major additions to existing U.S. shipbuilding and marine construction infrastructure.
- Single units can be constructed in 30 - 36 months.
- Overall construction time for a full five-unit MOB would range from 6.5 to 8 years.

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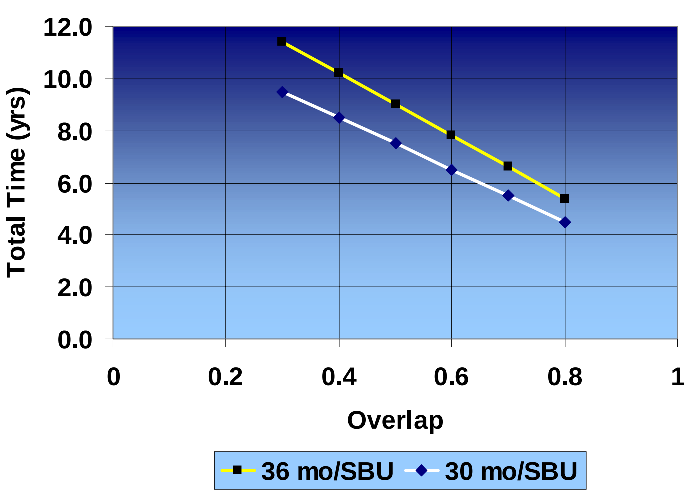

Figure 7 Total construction time vs. module overlap